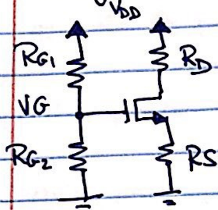
ECE 322L Spring 2020

Midterm examination I-Solutions

Design problem

One possible strategy to change the operating point of the transistor without altering the layout is to keep the load line fixed and move the Q point along the load line.



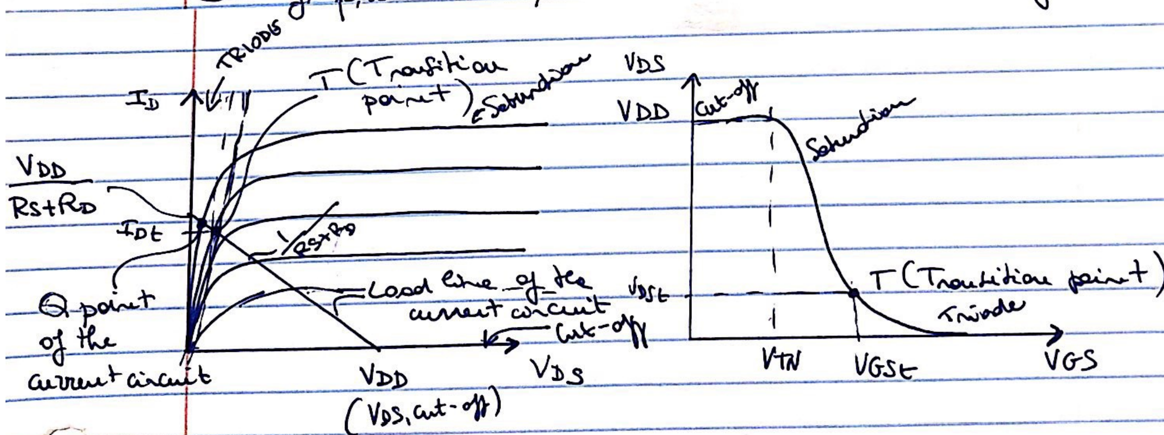
Load line

$$I_D = \frac{V_{DD} - V_{DS}}{R_D + R_S}$$

$$I_D = 0 \Rightarrow V_{DS} = V_{DD} = 5\,V$$

$$V_{DS} = 0 \Rightarrow I_D = \frac{V_{DD}}{R_S + R_D} = 3.3\,mA$$

We are basically setting V_{DD}, R_S, and R_D to the values provided in the original circuits, i.e., the one which operates in the linear region.
We choose to move the Q point along the load line towards saturation by lowering the V_{GS}.
See graphs below



As R_S is fixed at 0.5 kΩ, we can only lower the V_{GS} by lowering the V_G.

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$V_G = V_{DD}\dfrac{R_{G2}}{R_{G1}+R_{G2}}$

$V_{DD}\dfrac{R_{G2}}{R_{G1}+R_{G2}} - R_S I_{DQ,new} = V_{GSQ,new}$

Let $I_{DQ,new}$, $V_{GSQ,new}$, and $V_{DSQ,new}$ be the coordinates of the Q point in the middle of the saturation region.

$I_{DQ,new} = \dfrac{I_{Dt} - I_{D,cut\text{-}off}}{2} + I_{D,cut\text{-}off}$

$V_{DSQ,new} = \dfrac{V_{DS,cut\text{-}off} - V_{DS,t}}{2} + V_{DSt}$

$V_{GSQ,new} = \dfrac{V_{GSt} - V_{GS,cut\text{-}off}}{2} + V_{GS,cut\text{-}off}$

The subscript "t" indicates voltages and current at the transition point (between the saturation and the triode region).
The subscript "cut-off" indicates voltages and current at the cut-off point or the transition point between the cut-off and the saturation region.

$I_{D,cut\,off} = 0$ $\quad V_{GS,cut\text{-}off} = V_{TN}$ $\quad V_{DS,cut\text{-}off} = V_{DD}$

Next, we need to calculate the coordinates of the transition point T.
At the transition point:
$V_{DSt} = V_{GSt} - V_{TN}$
$I_{Dt} = K_n V_{DSt}^2$
$V_{DSt} = V_{DD} - (R_D + R_S) I_{Dt} = V_{DD} - (R_D + R_S) K_n V_{DSt}^2$
$K_n (R_D + R_S) V_{DSt}^2 + V_{DSt} - V_{DD} = 0$
$0.9125\,(1.5)\,V_{DSt}^2 + V_{DSt} - 5 = 0$
$1.368\,V_{DSt}^2 + V_{DSt} - 5 = 0$

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$$V_{DSt} = \frac{-1 \pm \sqrt{1+2.736}}{2.736} = \frac{-1 \pm 5.32}{2.736} \begin{cases} \cancel{-2.31}\,V \\ 1.58\ V \end{cases}$$

$V_{GSt} = 1.58V + 1 = 2.58V$

$I_{Dt} = 2.27mA$

$I_{DQ,new} \simeq 1.13mA$; $V_{DSQ,new} = 3.25V$; $V_{GSQ,new} = 1.75V$

Note that $V_{GSQ,new} > V_{TN}$ and $V_{DSQ,new} > V_{GSQ,new} - V_{TN}$, which means that the transistor is in saturation at this new Q point.

Now that we have calculated the coordinates of the Q point, we can use the values of $V_{GSQ,new}$ and $I_{DQ,new}$ to determine the required values of R_{G1} and R_{G2} to achieve the Q point in the middle of the saturation region.

$$V_{DD}\frac{R_{G2}}{R_{G1}+R_{G2}} - R_S I_{DQ,new} = V_{GSQ,new}$$

$$5\,\frac{R_{G2}}{R_{G1}+R_{G2}} - 0.5 \cdot 1.13 = 1.75$$

$$\frac{R_{G2}}{R_{G1}+R_{G2}} = 0.471 ; \quad \frac{R_{G2}}{R_{G1}+R_{G2}} = \frac{R_{G1}//R_{G2}}{R_{G1}} = 0.471$$

$$\frac{R_{G1}//R_{G2}}{R_{G1}} = 0.471$$

As $R_{G1}//R_{G2}$ determines the input resistance of the amplifier, it should be of the order of a 100s of kΩs to MΩs. Let's select $R_{G1}//R_{G2} =$ = 100 kΩ .

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$R_{G1} \parallel R_{G2} = 100\,k\Omega$

$\frac{100\,k\Omega}{R_{G1}} = 0.471$

$R_{G1} = 212.3\,k\Omega$

$\frac{R_{G1} R_{G2}}{R_{G1} + R_{G2}} = 100\,k\Omega$

$\frac{R_{G2}}{R_{G1} + R_{G2}} = 0.471$

$R_{G2} = 0.471\,R_{G1} + 0.471\,R_{G2}$

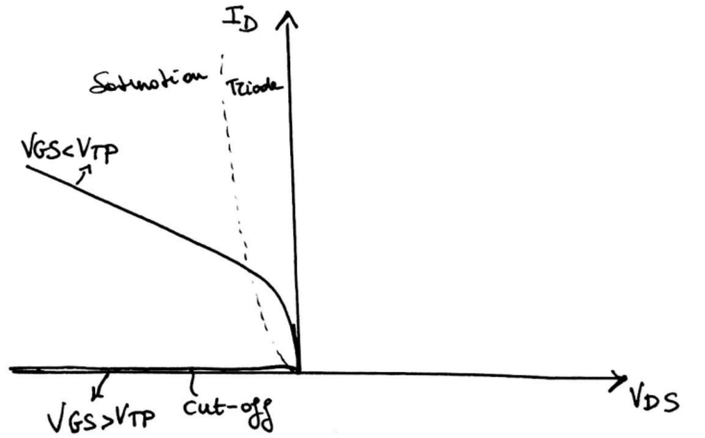
$R_{G2}\,(1 - 0.471) = 0.471\,R_{G1}$

$0.529\,R_{G2} = 0.471\,R_{G1}$

$R_{G2} = 189.02\,k\Omega$

Extra credit questions

1.



2. A resistor (Rs) between the source and ground in a common source amplifier is beneficial in DC because it improves the stability of the Q point by implementing a feedback loop between the output current (I_D) and the input voltage (V_{GS}). However, large R_S will also reduce the V_{DS} and bring the Q point close to the transition point or even out of saturation. As a result, the amplfied signal may be distorted. Additionally, R_S also decreases the small-signal voltage gain.